

- (13) Tannehill, I. R.: "Some Characteristics of Texas Rainfall," MONTHLY WEATHER REVIEW, vol. 51, p. 251. 1923. (A.)
- (14) "Report of the American Section of the International Water Commission, United States and Mexico," 71st Cong., 2d session, House Document No. 359, p. 371. Washington, 1930.
- (15) Schnurbusch, W. J.: Op. cit.,
- (16) Brooks, Charles F., and Fitton, Edith M.: "Weekly Succession of Gulf Stream Temperatures in the Straits of Florida," MONTHLY WEATHER REVIEW, vol. 58, p. 279. July, 1930. See also Page, John L. "Climate of Mexico," MONTHLY WEATHER REVIEW, Supplement No. 33, p. 9. Washington, 1929.
- (17) Potts, A. T.: Op. cit., pp. 7-8.
- (18) Tannehill, I. R.: "Recovery from Sub-normal Temperatures," MONTHLY WEATHER REVIEW, vol. 56, p. 365. (B) 1928.
- (19) Tannehill, I. R.: "Wet and Dry Northers," MONTHLY WEATHER REVIEW, vol. 57, p. 142. (C) 1929.
- (20) Reed, William G.: Atlas of American Agriculture, part 2, section 1, "Frost and the Growing Season," pp. 2-3. U. S. Dept. Agr., Washington, 1918.
- (21) Climatological Data, Texas section, April, 1930, p. 32. Houston, 1930.

ADDITIONAL CLIMATIC REFERENCES CONSULTED TO WHICH NO PAGE CITATIONS WERE MADE

- (1) Brooks, C. F.: "Distribution of Rainfall in Texas and New Mexico Accompanying the West Indian Hurricane of September

14-17, 1919," MONTHLY WEATHER REVIEW, vol. 47, pp. 640-641. 1919.

(2) Bunnemeyer, B.: "The Texas Flood of September, 1921," MONTHLY WEATHER REVIEW, vol. 49, pp. 491-494. 1921.

(3) Cline, Joseph L.: "The Climate of Extreme Southern Texas," Gulf Coast Magazine, vol. 3, No. 2, pp. 73-87. Kingsville, Tex., 1908.

(4) Hannemann, Dr. Max.: "Temperatur- und Windverhältnisse im Küstengebiet von Texas unter besonderer Berücksichtigung der 'Northers,'" Annalen der Hydrographie und Maritimen Meteorologie, Juni 1927, pp. 170-177.

(5) Kendrew, W. G.: The Climates of the Continents, Oxford University Press, Oxford, 1922.

(6) Kendrew, W. G.: Climate, Oxford University Press, Oxford, 1930.

(7) McAuliffe, J. P.: "Forecasting Rain on the West Texas Coast," MONTHLY WEATHER REVIEW, vol. 51, pp. 400-401. 1923.

(8) Tannehill, I. R.: "Severe Cold Waves on the Texas Coast," MONTHLY WEATHER REVIEW, vol. 56, pp. 41-46. 1928.

(9) Tannehill, I. R.: "Wind Velocities and Rain Frequencies on the South Texas Coast," MONTHLY WEATHER REVIEW, vol. 49, pp. 498-499. 1921.

(10) Tannehill, I. R.: "Some Inundations Attending Tropical Cyclones," MONTHLY WEATHER REVIEW, vol. 55, pp. 453-456. 1927.

(11) Williams, B. F., and Lowry, Robert L., jr.: "A Study of Rainfall in Texas," Reclamation Department Bulletin No. 18, Austin, Tex., 1929.

AERONAUTICAL METEOROLOGY IN GERMANY

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The following account of the work of the German national meteorological flying stations is taken from nine papers by Kurt Wegener, A. Lohr, H. Steinhäusser, H. O. Steiner, P. Lautner, and K. O. Lange that were read at one of the periodical meetings of the members of the service held at Hamburg on April 24-26, 1930, and subsequently printed in the Meteorologische Zeitschrift, volume 47, September 1930, page 325-345.

Daily airplane flights are made at Berlin, Hamburg, Darmstadt, Munich, and Königsberg. The ships and pilots belong to the national school for commercial pilots. The meteorological work is under the Imperial Ministry of Commerce.

The object of the flights is primarily the supplying of information for the benefit of air commerce, but experimental and research meteorology and the testing of aeronautical instruments are provided for by attaching a trained meteorologist to each ship. The resulting benefit to the meteorologists has been so great that it is proposed to make experience in the high meteorological ascents a prerequisite for all who have to do with issuing meteorological information to aircraft.

The flights are made simultaneously, to at least 5,000 meters (and a maximum of 7,360 meters has been attained. The peak altitude is timed to be reached at 8 a. m. Central European time when the observers on the ground are making the observation for the synoptic map. After the descent the results have to be reduced in time to be broadcast by radio at 10 a. m.

The daily flights were begun in April, 1927. During the year 1928 high flights were made on 86 per cent of all available flying days; in 1929 on 98 per cent. At Hamburg 45 per cent of the flights were "cloud flights" on which neither the ground nor the horizon was visible and it was necessary to rely on the gyroscopic level.

For the sake of quick reduction of the record sheets from the meteorographs, the ascent is made at an unchanging rate. Inversions are depended on to connect the different traces on the sheet. Sounding balloon observations have been used to check the results of the airplane records.

The first extensive series of such comparisons during the international observations of December, 1929, showed not only satisfactory correspondence of both temperature and humidity, but showed that the airplane meteorograph gave more detail on account of its more open scale.

The structure and transformations of clouds and their relation to the movements of the air masses of the Bjerknes polar front theory have been an important concern of the observers, and many important relations have been derived from observation. For example, "if the lower boundary of a continuous cloud sheet consists of fracto-stratus or fracto-nimbus then an airplane can emerge from the cloud sheet in descent without great danger, because the existing turbulence of the ground air layer always provides for the breaking of the lowest cloud zone.

"If a warm air wave comes in on the front of a depression, it is almost always indicated a day before by a formless haze in the southwest sky, while toward the other quarters of the sky the old air masses appear clear."

Some new cloud forms discovered on the high flights have received the names of their discoverers, viz, "Wegener air waves," "Lohr cloud stripes."

Thunderstorms are found to be observable at much greater distances, some as far away as France, Switzerland, and the North Sea. Studies of the vertical currents in and around cumulus show upward velocities of 2 to 4 meters per second; in cumulo-nimbus, 10 to 15. In front of line-squalls strong vertical bumpiness extends 3 to 4 kilometers, but this vanishes directly over the squall roll, and the space behind the squall head is very smooth. Further details regarding flights in clouds are contained in MONTHLY WEATHER REVIEW, November, 1931, pages 430 and 431.

Icing of airplanes has been a particular object of research. On 150 flights at Königsberg icing occurred on 16. The worst case was on December 17, 1929. After 9 minutes the temperature having fallen to -9.8°C ., the machine was suddenly covered with ice that reached a

thickness of 3 centimeters (1.2 inches). The unbalanced propeller threatened to tear the engine out of the ship, so that the pilot was forced down, but brought the plane under control at 300 meters above the "Haff" or lagoon, where the temperature was 3.2° C., and the ice melted off in flight.

The results of observation of icing of ships are summarized by Steiner as follows: Ice forms on airplanes (1) in tropical moist air, but not in continental warm air nor in purely polar air; (2) on leading edges of propellers and wings, etc., and spreads backward; (3) in temperatures of 0°C. to -24°C.; -6°C. to -12°C. are the most dangerous temperatures; (4) in isothermal as well as inversion clouds; (5) in gradients up to 0.9°C. per 100 meters; (6) only when the cloudy air is saturated with reference to water; (7) dependence on size of drops was not ascertained; (8) time of flight in cloud ranged from 1 to 25 minutes.

One respect in which the older kites and balloons are superior to airplanes is the observation of wind, provided the sky is clear. In and over clouds some progress has been made by range finding on audible signals from explosions and on radio signals from a radio transmitter. Steinhäusser, at Darmstadt, has been experimenting on estimates from the drift of airplanes determined by radio.

Oxygen-breathing apparatus has been the object of much experiment in the German aerological flights, but has been given up in routine work. The observers' objections are that the expanding oxygen freezes the tongue and teeth, and that they do not feel free enough for work or for a parachute jump when attached to the apparatus by strings and tubes. Nausea follows exposure to the thin air of high altitudes after some hours. The first effect of descent to normal pressure is a stimulation that enables the observer to get through the strenuous work of reducing his observations in time for broadcasting.

Atmospheric electricity is proposed as a subject for regular observation both with reference to thunderstorm electricity and the normal electrical state of the atmosphere. The latter observations are especially difficult in an airplane because the machine is kept highly charged by the exhaust. An instrument devised by Idrac is available for use either at the end of a long line or to be dropped in a parachute. The importance of the subject has only recently been realized through research on the relations of haze, cloud, and precipitation to the ionization potential gradient, mobility of ions, and other subjects hitherto considered only in the laboratory of colloid chemistry.

Quantitative measurements of thunderstorm electricity are also proposed, and the advice of Benndorf and Wigand, has been promised.

For photography the airplanes are equipped with a 25-centimeter (10-inch) airplane camera. The photographs obtained are of interest to the meteorologist, the airplane pilot, and for school instruction. Clouds naturally come in for the greatest share of attention. The narrow outlook between the wings, the vibration of the engine in ascent, and the fogging of the chilled lenses in descent introduce unusual difficulties.

Another German institution that is contributing to meteorology in an entirely unique way is the research institute of the Rhoen-Rossitten Association. The association is promoting sailing and gliding flight as a sport by providing flying fields, annual competitions, etc. The institute is taking advantage of the opportunities that such flight affords of obtaining scientific insight into

the aerodynamical and meteorological conditions requisite for air transport of all kinds.

The following account of the institute is drawn from a paper by the director, Dr. Walter Georgii, *Ten Years Gliding and Soaring in Germany*, (Quarterly Jour. Roy. Met'l Soc., v. 56, Apr., 1930, p. 141-150), from the annual report for 1929 of the director, and a review of this report by Sir Gilbert T. Walker, in the *Quarterly Journal* for July, 1931 (v. 57, p. 340-344).

The work of the institute on the design of aircraft and on flight technique will not be discussed here, but the work on vertical currents, especially under cumulus clouds and in storm fronts, will be outlined.

There have been three stages in the development of the sport of gliding and soaring. First came the use of local rising currents over every irregularity of the earth's surface; e. g., knolls, dunes, woods, even the waves of the sea may be used for soaring flight. The work of the association is centered around two well-known soaring grounds, the Wasserkuppe on the Rhoen hills east-northeast of Frankfurt and Rossitten on the sandy coast of eastern Prussia.

Increasing familiarity of pilots with the local conditions around these hills enabled them to increase the duration of soaring flight from 2 minutes 22 seconds and 1,830 meters length on the first flight by Klemperer in 1920 and 1 hour by Hentzen and Martens in the *Vampyr* in 1922 up to 8 hours 24 minutes by Neiningen at Wasserkuppe and 14 hours 43 minutes by Dinort at Rossitten in 1929.

The second stage of advance was the use of ascending currents under cumulus clouds. These free pilots from the local topography and enable them to undertake cross-country flights.

The technique may be illustrated by one example: Kronfeld started from the western slope of the Wasserkuppe and flew at once toward an approaching cumulus cloud, which he followed toward the east with continual gain of height, reaching finally 470 meters above the starting point. The cloud began to dissipate and the up current became ineffective, so that Kronfeld left it at once and flew with considerable loss of height to the Himmelsdankberg, the turning point of the official course, and then, flying always from cloud to cloud, he returned to the Wasserkuppe at his maximum height of 540 meters above the starting point. Further development may be measured by the following instances: On July 30, 1929, Groenhoff, with a passenger in the 2-seater glider *Rhonadler* flew under a cumulus and rose through it almost to its summit, reaching a maximum altitude of 1,250 meters above the starting point and then flew a course of 33.3 kilometers. On the same day and under the same conditions Kronfeld was carried up to 2,150 meters and made a cross-country flight from Wasserkuppe to Bayreuth, 150 kilometers, in 4 hours.

The third and most recent development has been the use of up currents in front of line squalls. In the longest of these flights Kronfeld started at the moment when the wind was freshening just before the arrival of the line squall, and, by utilizing the rising current just before the cold front, rose 2,000 meters. He then flew about 2 kilometers in front of the squall, rising or falling slightly as he was nearer or farther from the front. He finally turned away from the front and landed 143 kilometers away from the Wasserkuppe after four and one-half hours flight.

It is in the scientific study of the phenomena revealed by the flights that the institute is doing such important work. For this purpose light airplanes have been built, with engines as small as 8 horsepower. The normal rate

of ascent and the falling velocity of these has been determined, so that placing the plane in any given situation enables the upward current to be determined. Measurements have been effected up to 4 kilometers, and enough material has been accumulated to enable general conclusions to be derived as to the intensity, vertical extent, and the cause of vertical movements in relation to heat conditions, vertical distribution of horizontal wind velocity, and weather conditions.

Doctor Raethjen, whose health has now given way, developed an extraordinarily accurate kinematographic

measuring apparatus for following from two bases the flight of a soaring plane or small balloon.

In the study of streamlines in the free atmosphere, pilot balloons with no lift are carried up by airplane and released at definite places. This work is being extended to the study of turbulence.

The work of the institute is being greatly handicapped by the present financial situation in Germany. The subsidy from the State was reduced one-third in 1929, and three of the scientific posts had to be allowed to lie vacant.

METEOROLOGICAL CONDITIONS DURING THE FORMATION OF ICE ON AIRCRAFT¹

By L. T. SAMUELS

[Weather Bureau, Washington, D. C., Dec. 1932]

(Author's abstract)

Ice is found to collect on a plane in appreciable amounts only when the plane is in some form of visible moisture such as cloud, fog, mist, rain, etc., and the air temperature is within certain critical limits. There are two principal types of ice formation found under such conditions, viz, clear ice and rime. Of these, clear ice forms the greatest hazard in that it adheres more firmly to the plane and decreases its lifting qualities markedly. A third type, viz, frost, is of lesser importance, as it has very little resistance to the vibration and wind force encountered in flight.

The records of ice formation obtained at four Weather Bureau airplane stations were classified according to the two general types of formation, viz, clear ice and rime, together with the respective temperatures, relative humidities, clouds and elevations above ground at which the formations occurred. This classification includes 108 cases where rime formed, 43 cases in which clear ice formed and 4 cases when both rime and clear ice formed during the same flight.

It is found that both clear ice and rime formed over practically the same range of temperature, viz, 0° C. to -18° C. and 0° C. to -20° C., respectively, showing that temperature alone can not be used as a criterion for indicating which type of formation will occur on any particular occasion. It is thus concluded that one or more other factors are decisive in determining the type deposited.

The temperatures at which the most frequent deposits occurred were higher for clear ice (-4° C. to -5° C.) than for rime (-6° C. to -7° C.). These values agree closely with those found by Peppler (1) from kite observations. The latter indicated that clear ice formed at an average temperature of -4° C. and rime at -6° C. It is found that 58 per cent of the total number of clear ice formations occurred at temperatures at or above -5° C., whereas only 37 per cent of the total number of rime formations occurred over this temperature range.

A very pronounced maximum frequency of occurrence of both clear ice and rime was found at relatively low heights, viz, between 500 and 1,000 meters above ground. Secondary maximum frequencies were found between 2,500 and 3,000 meters for clear ice and between 4,000 and 4,500 meters for rime. These primary and secondary maximum frequencies of occurrence are possibly related to layers of maximum condensation (cloudiness). Both types of formation occurred throughout the same strata and with small and practically equal percentages of frequency at the lowest and greatest heights reached. The maximum heights where icing occurred coincide with the maximum heights of the flights.

Both clear ice and rime formed most frequently in St. Cu. clouds. Comparatively high percentage frequencies of clear ice formations occurred in A. St. clouds, and of rime in St. clouds; when in rain, but not in cloud, the formation was always clear ice.

An examination of the prevailing temperature lapse rates occurring in these observations showed no relationship between the lapse rates and the type of ice formation.

The ratios between the number of occurrences of rime and of clear ice deposits vary considerably for the four stations used. This ratio for the observations for all stations combined was 2.5 to 1.0, with a preponderance of rime. These ratios (rime: clear ice) for the individual stations are as follows: Chicago, 1.7; Cleveland, 7.5; Dallas, 5.5; and Omaha, 0.6.

It seems probable that, in general, large droplets tend to form clear ice, whereas small droplets usually produce rime. Small droplets, in general, freeze more rapidly than do large droplets.

The resultant effects of partial freezing, evaporation, and rate of conduction of heat away from water deposits on the plane appear to be of prime importance in determining the type of deposit.

The suggestion by various authors that supersaturation with respect to ice in clouds composed of subcooled water droplets is responsible for comparatively sudden and heavy ice deposits as occasionally reported by pilots is shown by Humphreys (2) to be inadequate. If we assume a condition of supersaturation with respect to ice at a temperature of -10° C.; and if all the excess vapor in the air were deposited on the plane, it would be equivalent to a layer of clear ice 1 inch thick on the front of a plane after the latter had flown for a distance of 72 miles. Furthermore, it is probable that only a small part of the excess vapor encountered would be deposited on the plane.

In connection with the occurrence of undercooled cloud droplets at low temperatures it is noted that A. Wegener (3) observed a "fog bow" in Greenland at -34° C.; also, W. C. Haines (4) observed rime formations in the Antarctic produced by fog at temperatures of -26° C., -30° C., and -44° C. The manner in which water exists in the liquid state at such low temperatures is not fully understood.

The results of this investigation show that the danger of ice formations can be avoided only by avoiding visible moisture, particularly liquid water clouds or rain, when the temperature is at or below freezing.

One of the chief difficulties in a study of this kind is the frequent impossibility of determining which type of

¹ Complete paper published by National Advisory Committee for Aeronautics Technical Note No. 439. Washington, D. C., 1932.